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FINAL PROGRESS REPORT

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ABSTRACT

Eye movements are needed to acquire visual information because clear vision is available only at the center of the retina. The main objectives of the research are to understand the cognitive and sensory factors underlying the control of eye movements, and to understand how visual processing depends on the eye movements used to inspect displays.

Experiments were completed showing that: (1) smooth pursuit becomes poor when the frequency of target motion exceeds 0.5 Hz even when the amplitude of motion is small (<30') so that average target velocity is low (Martins et al., 1985); (2) the acquisition of information from visual displays is not limited by the directional pattern of saccades but is limited by size: small (<30') saccades, required to inspect small details not forming recognizable visual patterns, cannot be controlled accurately without latencies of several hundred milliseconds (Kowler and Anton, 1987); (3) the discrimination of velocity by smooth eye movements is about the same as the perceptual discrimination of velocity, (Kowler and McKee, 1987); (4) saccades can be planned in sequences of 1 to 5 movements, rather than one saccade at a time (Zingale and Kowler, 1987); (5) voluntary selection of the target for smooth eye movements involves an attentional mechanism in that performance on visual tasks is better for the stimuli selected as the target than for the background stimuli (Kowler and Zingale, 1985; Khurana and Kowler, 1987); (6) motor preparation rather than automatic sensory averaging is responsible for effects of background stimuli on saccades (He and Kowler, 1987).



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FINAL PROGRESS REPORT

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Objective

Eye movements are needed to acquire visual information because clear vision is available only at the center of the retina. The main objectives of the research are to understand the cognitive and sensory factors underlying the control of eye movements, and to understand how visual processing depends on the eye movements used to inspect displays.

Brief description of progress

Experiments were completed showing that: (1) smooth pursuit becomes poor when the frequency of target motion exceeds 0.5 Hz even when the amplitude of motion is small (<30') so that average target velocity is low (Martins et al., 1985); (2) the acquisition of information from visual displays is not limited by the directional pattern of saccades but is limited by size: small (<30') saccades, required to inspect small details not forming recognizable visual patterns, cannot be controlled accurately without latencies of several hundred milliseconds (Kowler and Anton, 1987); (3) the discrimination of velocity by smooth eye movements is about the same as the perceptual discrimination of velocity, (Kowler and McKee, 1987); (4) saccades can be planned in sequences of 1 to 5 movements, rather than one saccade at a time (Zingale and Kowler, 1987); (5) voluntary selection of the target for smooth eye movements involves an attentional mechanism in that performance on visual tasks is better for the stimuli selected as the target than for the background stimuli (Kowler and Zingale, 1985; Khurana and Kowler, 1987); (6) motor preparation rather than automatic sensory averaging is responsible for effects of background stimuli on saccades (He and Kowler, 1987).

Publications

Martins, A.J., Kowler, E., and Palmer, C. (1985) Smooth pursuit of small amplitude sinusoidal motions. Journal of the Optical Society of America A, 2, 234-242.

Kowler, E. and Zingale, C. (1985) Smooth eye movements as indicators of selective attention. In Attention and Performance XI. Edited by Posner, M.I. and Marin, O.S.M. L. Erlbaum, Hillsdale, NJ., pp. 285-300.

Kowler, E. and McKee, S.P. (1987) Sensitivity of smooth eye movements to small differences in target velocity. Vision Research, 27, 993-1015.

Kowler, E. and Anton, S. (1987) Reading twisted text: Implications for the role of saccades. Vision Research, 27, 45-60.

Zingale, C. and Kowler, E. (1987) Planning sequences of saccades. Vision Research, 27, 1327-1341.

Khurana B. and Kowler E. (1987) Shared attentional control of smooth eye movements and perception. Vision Research, 27, 1603-1618.

He, P. and Kowler, E. The role of voluntary decisions in the programming of saccades: Implications for "center-of-gravity" tendencies. Submitted.

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Talks

Zingale, C. and Kowler, E. Programming sequences of saccades. Association for Research in Vision and Ophthalmology, May, 1985.

Zingale, C. and Kowler, E. Programming sequences of saccades. Third European Conference on Eye Movements, September, 1985.

Kowler, E. Cognitive and sensory determinants of human eye movement. Colloquium given at Rutgers University, September, 1985, and Columbia University, November, 1985.

Kowler, E. Sensory determinant of human eye movement. AFOSR, Bolling AFB, June, 1986.

Khurana, B. and Kowler, E. Shared attentional control of smooth eye movement and perception. Association for Research in Vision and Ophthalmology, March, 1986.

Khurana, B. and Kowler, E. Shared attentional control of smooth eye movement and visual information processing. Psychonomic Society, November, 1986.

He P. and Kowler E. Motor preparation as a determinant of the accuracy of short latency saccades. Association for Research in Vision and Ophthalmology, May, 1987.

Detailed summary of progress

(1) Smooth pursuit of small amplitude sinusoidal motions (Martins, Kowler and Palmer): Smooth pursuit of sinusoidal motions became poor when target frequency exceeded 0.5 Hz. Poor pursuit (characterized by low gain and systematic drifts away from the target) was observed even though target amplitude was small (<30') so that both velocity and acceleration were low enough to expect good pursuit based on prior work. These results raise the possibility that retinal motions with temporal frequencies greater than 0.5 Hz, which will not be corrected by smooth eye movements, are particularly valuable for vision. Such high temporal frequencies are often found during attempts at steady fixation while the head is free to move.

(2) Reading twisted text (Kowler and Anton, 1987): These experiments investigated the extent to which the quality of oculomotor skill limits the acquisition of information from visual displays. Limits are expected based on several prior studies of target step-tracking showing that saccadic latency varies with the direction of saccades, the direction of prior saccades and the size of saccades. In the present experiment subjects read text in which the direction of saccades was varied by reversing the order of words in a line, the order of letters in a

word, or both. Some of these transformations also drastically altered the customary appearance of words. To separate visual from oculomotor influences on reading, letters were rotated 180 deg to produce text in which the order of words and/or letters was normal, but the customary visual appearance of words was destroyed. We found that the order of words and letters, by themselves, did not affect the speed of reading text under the instruction to maintain perfect reading accuracy. Altering the visual appearance of words, however, slowed reading speed by a factor of 10. The decrease in reading speed was due in part to the subjects' need to make small (<30') saccades to look at each letter of the transformed words that were hard to recognize. Frequent use of small saccades slows reading because their latencies are long. Long latencies are due to oculomotor, not cognitive factors: similar long latencies were observed when saccades were used to track a point whose motion mimicked the subjects' own reading eye movement patterns. These results show that visual information acquisition is limited by saccade size and not by saccade direction. The limitations imposed by saccade size come into play whenever nearby visual details do not form recognizable patterns, thus requiring serial inspection by saccades for accurate visual recognition.

(3) Sensitivity to velocity differences (Kowler and McKee, 1987): The quality of smooth pursuit is traditionally assessed by average gain (average eye velocity/target velocity). Average gains of 1 are considered to represent perfect pursuit despite the fact that gain is seldom 1 on any given trial, but varies considerably from trial to trial. The variability of smooth pursuit was studied by measuring "oculomotor difference thresholds," the smallest difference between target velocities that produces a reliable difference in eye velocities. We found poor discrimination, along with high average gain, during the first 1/2 second of pursuit. Discrimination improved over time reaching levels found for perceptual velocity discrimination by about 600-700 msec after the onset of target motion. The fact that smooth eye movements can achieve a level of precision characteristic of perceptual performance suggests that common sensory representations of target motion may serve each. Nevertheless, such sensory representations play a surprisingly small role in guaranteeing the retinal velocities optimal for vision. This conclusion is based on our findings that (1) eye velocity depended on the velocity of targets in prior trials and (2) the eye never got off the ground with brief (200 msec) duration motion, but easily reached velocities close to target velocity by 200 msec after the onset of long (1000 msec) duration motion. These findings show that expectations and practice allow the eye to track the target it is most likely to encounter, thus avoiding large position and velocity errors. Sensory information about the velocity of the current target serve only to fine-tune an already acceptable pursuit response.

(4) Planning sequences of saccades (Zingale and Kowler, 1987): Studies of saccades traditionally assume that saccades are planned one at a time. By contrast, studies of other voluntary motor responses, such as typing or speech, have shown that responses are planned as whole sequences characterized by specific temporal and spatial relationships among the individual responses. The capacity to plan sequences of saccades was demonstrated by asking subjects to make saccades to look at 1 to 5 stationary points located at the vertices of an imaginary pentagon. Latency of the first and subsequent saccades increased as sequence length increased from 1 to 5 targets. Also, saccadic latency depended in idiosyncratic ways on the ordinal position of a response in a sequence. Similar results were obtained for saccades to remembered target locations. The demonstrated capacity to plan sequences of saccades may be useful for the acquisition of visual information. Sequences may be planned in advance and then

executed automatically, leaving the observer free to attend to the content of the visual display.

(5) Smooth eye movements and selective attention during a detection task (Kowler and Zingale, 1987): When the visual field contains superimposed stationary and moving stimuli, smooth eye movements maintain the line of sight on the stimulus selected by the observer. There is virtually no effect ($<4\%$) of the background stimulus (Kowler et al., 1984a). To find out whether the attentional mechanism used to determine the target for smooth eye movements is the same as the attentional mechanism used to enhance the perceptual processing of selected visual details subjects performed concurrent oculomotor and visual tasks. The oculomotor task was to maintain the line of sight on one of two superimposed fields of random dots, one stationary and the other moving rightward at about 1 deg/sec. The perceptual task was to detect the disappearance of a subset of dots from either field. Subjects were better at detecting dots disappear from the target field, suggesting a common attentional mechanism for smooth eye movements and perception.

(6) Smooth eye movements and selective attention during visual search (Khurana and Kowler, 1987). This experiment showed that superior perceptual performance for the target for smooth eye movements was not due to the lower retinal velocity of the target relative to the background. Subjects searched a 4x4 array of horizontally moving characters for the presence of two numerals, one located in either the first or third, and the other in either the second or fourth, rows. The velocity of the second and fourth rows (50'/s or 100'/s) was twice the velocity of the first and third rows. Subjects matched eye velocity to either the slower or the faster rows while maintaining vertical eye position at the center of the array. Search performance was about 20%-30% better for the target rows than for the background rows. The target was better even for those instances when imperfect tracking led to equal retinal velocities for target and background, shows that attention, not retinal velocity, accounted for superior performance with the target. This result suggests a common attentional mechanism for perception and smooth eye movement. A common mechanism implies that interpretation of perceptual judgements made about background stimuli while subjects fixate superimposed targets must take into account not only the retinal velocity of the background but the cognitive requirements (i.e., attention) of the fixation task.

(7) Sensory contributions to saccadic planning (He and Kowler): Saccades have been believed to be capable of a rapid averaging response. This is a special mode of responding believed to be under the control of sub-cortical structures in which saccades are directed to the average location of all stimuli in the field (Ottes et al., 1985). The present experiments showed that what has appeared to be sensory averaging is actually a strategy of directing saccades to a location where the target is most likely to appear. This conclusion is based on experiments showing that probabilistic considerations, rather than the configuration of the stimulus, determine the endpoint of saccades. The sub-cortical averaging process described by prior workers would not be sensitive to probabilities. Sensory averaging as typically conceived does not exist. The problem for understanding saccades is to find out how plans formulated before targets appear interact with newly acquired information in order to produce saccades that permit efficient visual scanning.